PROBLEMS IN THE DETERMINATION OF THE BASAL METABOLISM OF MAN AND FACTORS AFFECTING IT

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Our lives are continually maintained by the processes of heat production. As long as we produce heat, we are alive, and when heat production stops, living ceases. Thus the end result of our various activities is heat production. There is a minimum level of heat production below which we can not live for any length of time. This minimum level of heat production is the result of internal glandular and cellular activity, and of respiration and circulation. When we measure this heat production with the body in a resting, quiet condition without external muscular activity, and after the effects of the last ingested food have ceased, we call it the basal metabolism. We shall consider in this lecture some of the problems in the measurement of basal metabolism and some of the factors that affect the basal metabolism.

Effect of neutral bath. Ordinarily the basal metabolism is measured with the subject in a comfortable condition so far as the sensation of cold or warmth is concerned. In the laboratory this usually means with the ordinary clothing and, if the temperature is about 20° Centigrade, there may be a light covering of blankets. Usually, however, the amount of clothing and covering of the subject during basal metabolism measurements is not reported by the investigator, and Lefèvre (1) has criticized this procedure. He maintained that in practically all basal metabolism measurements, as ordinarily made, the conditions for heat loss are such that the metabolism is higher than the true basal. According to him the true basal metabolism can be obtained only when the subject is immersed in a water bath at 35° to 36° C., because under other conditions there will be an excess heat production to combat the loss of heat to the environment. To meet this criticism tests were made by F. G. and C. G. Benedict (2) with several subjects in which the basal metabolism was first determined with the subjects lying clothed and lightly covered at a temperature of 15°, in order to accentuate the possible influence of a cool environmental temperature. After these measurements were made, the subjects entered a neutral bath at 34° to 35° C. in a warm room and the observations were repeated under these conditions.

The results in Table I indicate that there was no decrease in the metabolism due to immersion in a bath at nearly body temperature. If anything, there was a slight tendency to an increase in the metabolism. After the bath the subject's metabolism returned to the basal value quickly. The contention of Lefèvre was thus not substantiated. It is obvious that the determination of basal metabolism by immersion in a bath would be highly impracticable. Furthermore, the tendency for the metabolism to increase during the bath emphasizes the necessity for not having too heavy covering on the subject, as this might lead to a physiological fever with a consequent rise in metabolism.

TABLE I.

MR. B; AGE, 47 YEARS; NUDE WEIGHT, 67 KG.; HEIGHT, 169 CMS.

(Oxygen consumption in c. c. per minute.)

DATE	BASAL (Room Temp. 16°–18° C.)			BATH AT CIRCA 36.0° C.					
October 4	204	205	197	208	215	210	202	......	......
October 5	203	207	200	211	222	223	224	230	......
October 6	196	220	213	212	213	215	211	236	224

Minor muscular movements. It is generally recommended that the subject remain perfectly quiet during the period of measurement. It is difficult for some people to understand what perfectly quiet means. They are apt to change the position of the legs, or to raise the hand to the face to scratch, if a slight itching or irritation takes place. One always seems to have a desire to do these things just at the wrong time. Lefèvre of Paris criticized the emphasis laid on the complete absence of muscular activity and calculated from the foot pounds required to raise the hand to the head that it would require an extremely small amount of energy. In order to test the effect of slight movements on the metabolism, F. G.

and C. G. Benedict (3) studied two well-trained subjects in the Nutrition Laboratory in which measurements were made under basal conditions and then during periods when the subject raised the hand to the forehead every four seconds. The results are shown in Table II.

TABLE II.

INFLUENCE UPON THE OXYGEN CONSUMPTION OF SMALL MUSCULAR MOVEMENTS OF ARMS AND LEGS.

SUBJECT A			SUBJECT B		
Date and Condition[1] 1924	Period	Oxygen Consumption per Minute c. c.	Date and Condition[1] 1924	Period	Oxygen Consumption per Minute c. c.
January 3			February 29		
Basal	I	193	Basal	I	256
Basal	II	188	Basal	II	255
Arm movement	III	218	Basal	III	253
Basal	IV	195	Arm movement	IV	280
January 7			March 1		
Basal	I	200	Basal	I	257
Basal	II	196	Basal	II	255
Arm movement	III	210	Basal	III	244
Basal	IV	193	Arm movement	IV	268
Leg movement	V	222	Leg movement	V	285
January 9					
Basal	I	203			
Basal	II	189			
Arm movement	III	224			
Leg movement	IV	209			
Basal	V	189			
January 16					
Basal	I	202			
Basal	II	195			
Arm movement	III	215			
Leg movement	IV	225			
Basal	V	200			

[1]In basal periods subjects were lying, clothed, and covered with light blanket. In the arm movements the hand was raised to the forehead every 4 seconds. In the leg movements the feet were crossed every 20 seconds.

The actual increase proved to be only 1.5 cc. of oxygen for each movement. In another series, the subject crossed and uncrossed the legs every 20 seconds. One such leg movement every minute would raise noticeably the basal metabolism. Although single minor muscular movements, such as raising the arm to the head, have but little influence on the basal metabolism, movements of the legs must be denied. It is unsafe to disregard any of the stringent rules for quiet muscular repose. It is best to do everything possible to get the subject into a comfortable, relaxed position so that there will be no desire to change the position. The operator should have everything as free as possible from little annoyances, such as wrong lights, jarring the bed, and slamming doors.

Effect of previous activity. Benedict and Crofts (4) showed that the basal metabolism was not raised by the muscular exercise of rising, bathing, dressing, walking in wintry weather for 10 minutes, and climbing 3 flights of stairs, provided that

TABLE III.

OXYGEN ABSORPTION AND PULSE RATE PER MINUTE OF COLLEGE WOMEN BEFORE AND AFTER RISING.

Subject No.	Oxygen Absorption		Pulse Rate	
	Before Rising	After Rising	Before Rising	After Rising
	c. c.	c. c.		
II	243	249	56	51
III	193	196	65	63
IV	190	200	56	55
V	173	175	57	56
VI	170	170	59	56
VII	182	186	59	57
VIII	170	165	62	58

after such exercise the subject was clothed and lay quietly for 30 minutes, lightly covered, in a room at circa 20° C. Values secured under such conditions were compared with those obtained after a night's sleep in bed before the subjects arose and went through the activity previously described. Table III gives a summary of the results.

Constancy from hour to hour. Some of the questions that arise in connection with the determination of basal metabolism are, how many periods of measurement shall there be on the same day, and how shall we make a selection from the results, or shall we average all that we obtain? Certainly we should not depend on one observation and it is better to have three periods, if possible. Then we may consider the first period as one of adjustment and average the results of the other two. Some years ago, in a study of the comparative accuracy of different types of respiration apparatus, (5) I came to the conclusion that in three successive periods the oxygen consumption should not have a greater range than 10 c.c. This would mean a 5 per cent range, if the average oxygen consumption were 200 c.c. per minute. Since that time I have come to the conclusion that this is too rigid a standard to demand in all cases, and that with untrained subjects a greater range would have to be allowed, probably 15 c.c. at a level of 200 c.c. per minute. As a general rule, it is not wise to make observations for more than three periods, rejecting the first if materially higher than the others, or averaging all three. Subjects usually become fatigued or restless after three periods,

TABLE IV.

CONSTANCY IN BASAL METABOLISM IN CONSECUTIVE 10-MINUTE PERIODS.

(Mr. C., January 26, 1925.)

Period	Oxygen Consumed Per Minute	Period	Oxygen Consumed Per Minute
	c. c.		c. c.
I	219	VII	225
II	220	VIII	229
III	219	IX	223
IV	230	X	223
V	223	XI	222
VI	225		

and then the metabolism rises. Table IV shows that with a well-trained subject it is possible to obtain a series of 10 periods with a narrow range in values (6).

Constancy from day to day. Not only are we concerned in the constancy of the basal metabolism on the day of measurement, but also the range of values from day to day is of importance in any study of metabolism. It is the practice in some laboratories to determine the basal metabolism on several days and then use the average of these days' measurements as a base-line for comparison with measurements under other conditions on days when the determination of the basal metabolism is omitted. This may be justifiable when the effect of the superimposed factor is large, but hardly acceptable when only slight differences are expected. As a rule, rarely, if ever, do we use an average basal value derived from measurements on several days to calculate the effect of a superimposed factor.

It is always best to determine the basal metabolism on the same day and under the same conditions as those under which the superimposed factor is to be studied. In 1921 a statistical analysis made by Harris and Benedict (7) on 11 subjects who had been studied from 20 to 53 days led to the general finding

TABLE V.

VARIATIONS IN OXYGEN ABSORPTION FROM DAY TO DAY.

Subject	Number of Experiments	Range of O_2	Average O_2	Coefficient of Variation
		c. c.	c. c.	
J. C.	40	198–231	210	3.4
J. C.	55	202–235	215	3.5
J. C.	31	207–232	222	2.4
J. C.	36	210–251	227	3.4
C. M. B.	41	238–283	257	3.6

of a coefficient of variation of 4 per cent of the average metabolism. During the past few years we have had several series of experiments with one subject and one series with another varying from 31 to 55 days. Table V shows the results, which are of about the same order as those obtained by Harris and

TABLE VI.

CONSTANCY IN BASAL METABOLISM ON CONSECUTIVE DAYS.

(Mr. C.)

Date	Oxygen Consumed Per Minute	Date	Oxygen Consumed Per Minute
	c. c.		c. c.
April 21........	217	May 5.......	216
April 22........	215	May 10.......	225
April 23........	214	May 19.......	221
April 24........	218	June 24........	226
April 25........	229	June 25........	219
April 28........	222		

Benedict. The highest result with C. M. B. was on the first day. In all of the measurements this subject was sitting but post-absorptive, as was also J. C. in the third series. An example of low daily variation is shown in Table VI, (8) when J. C. was studied on 11 different days.

Seasonal variations. In the course of the year there are marked variations in the external temperature, which in our latitude ranges from 100° F. in the shade with high humidity in summer to 10° below 0° F. with low humidity in winter. We try to accomodate ourselves to these conditions by change in amount and character of clothing, to some extent by lessening activity in summer, and also by an attempt at artificial cooling (consumption of iced drinks and foods). The question, however, arises as to whether there may not be a seasonal variation in basal metabolism which may occur in spite of our attempts to adapt ourselves to climatic and seasonal changes. In order to obtain some information on the possible occurrence of a seasonal variation, Gustafson and Benedict (9) made a

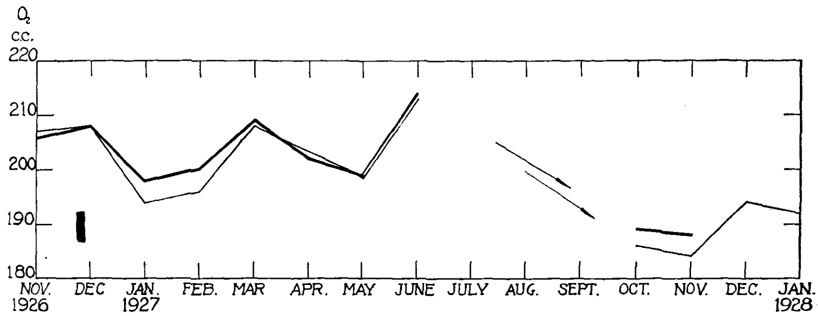

FIGURE 1. Course of the oxygen consumption of young women with the change in season. The light black curve represents the average for five subjects, the heavy black curve that for eight subjects.

series of measurements of the basal metabolism of 20 Wellesley College students once each month from October, 1926 to January, 1928 with the exception of July, August, and September. In Figure 1 the light line curve shows the course of the average basal oxygen absorption of five young women and the heavy line curve that of eight subjects. There was a low metabolism during the winter followed by a higher level in the spring. The low level in May may possibly be due to the relatively large number of observations during menstruation. In the course of a series of measurements on a well-trained male subject we have observed that the metabolism tends to be higher in the spring than at any other time. The cause for the change in metabolism is not known. It can scarcely be due to a rise in external temperature, as the temperature is higher later in the year.

Menstruation. When the basal metabolism of normal women between the ages of puberty and the menopause is determined, it is usually recommended that the observations be taken on days outside the menstrual period. A number of studies have been made on the basal metabolism during the menstrual period as compared with that during the non-menstrual interval. Hitchcock and Wardwell (10) in this institution have reported a series of 800 tests on 27 women. Selecting the results on 20 women, they found that 14 showed a lowering of the basal metabolism during the menstrual period. Benedict and Finn (11) studied the day to day varia-

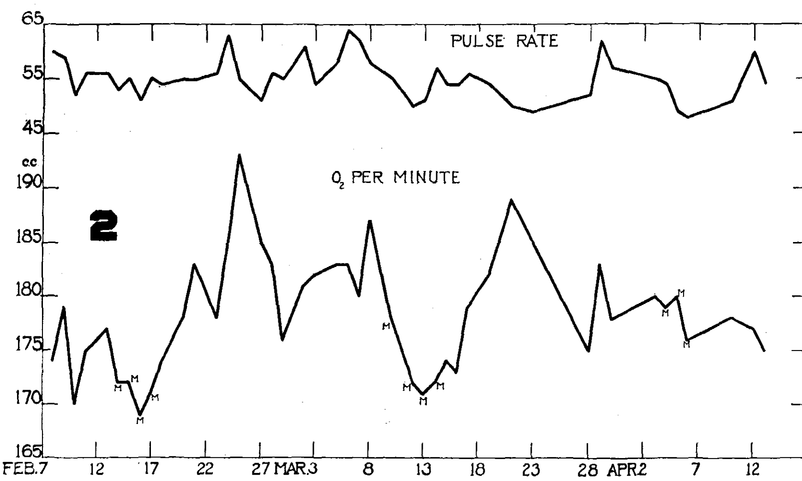

FIGURE 2. Oxygen consumption (cc.) and pulse rate per minute of Miss W. from day to day throughout a period of two months, including three menstrual cycles. The menstrual days are indicated on the oxygen curve by the letter M.

tion on a well-trained subject for two months, including three menstrual cycles. Figure 2 shows the daily variations in oxygen absorption and pulse rate for this subject covering more than two months. The menstrual days are designated M. In all three menstrual periods the metabolism was lower than that obtained during the remaining portion of the month.

Metabolism before and after vacation. In the course of a number of years, observations have been made on the metabolism of members of the staff of the Nutrition Laboratory (12) before vacation, usually in July, and then again as soon as possible on their return to laboratory activities, usually in September. The number of subjects studied varied from year to year, and a series of observations was made in 4 different years, 1918, 1920, 1925, and 1927. In Table VII is given a summary of the average results obtained each year. The groups were not the same each year, and consequently the average values vary. The table includes data on the body weights and the pulse rates as well as the oxygen absorption. In general, most of the individuals gained weight during the vacation although this was not invariably the case. In some cases there were gains of as high as 4 kilos during vacation. This is reflected in the general average of the body weights. In spite of this, however, the averages for three of the four groups indicate practically no change in the oxygen absorption measured in the basal condition.

TABLE VII.

AVERAGE BASAL METABOLISM BEFORE AND AFTER A VACATION.

YEAR	NUMBER OF SUBJECTS	BODY WEIGHT (kilos)		OXYGEN PER MINUTE (c. c.)		PULSE RATE PER MINUTE	
		Before	After	Before	After	Before	After
1918.......	9	54.1	55.4	188	188	64	64
1920.......	5	56.5	58.3	195	189	65	64
1925.......	5	63.6	63.4	200	221	61	66
1927.......	9	60.8	61.3	187	190	63	62

In 1925 three of the group showed marked increases in metabolism. Thus, in one case the oxygen absorption increased from 142 to 172 cc. per minute and in another case from 254 to 273 cc., that is, gains of 21 and 8 per cent, respectively. In none of the individuals in the other three series was there any pronounced change in the metabolism. Also, in this group in 1925 there was a marked increase in pulse rate. Most of this increase, however, is due to a change in the pulse rate of one individual from 55 before vacation to 82 after vacation. One of the same subjects who showed a marked increase in 1925 also showed an increase in 1927.

These studies, however, indicate, as a whole, that the vacation does not result in any change in metabolism. This is surprising and speaks for a marked fixity in basal metabolism which seems to be unaltered even when pronounced subjective impressions of recuperation and betterment are expressed. In view of the present fad for sun tanning it may be advisable or desirable to have additional studies in which the possible effect of exposure to sunlight is specifically studied.

Body temperature. It is well known that the metabolism is raised during fever. Du Bois (13) found that for each degree Fahrenheit rise in body temperature the metabolism was increased 7.2 per cent. The possibility of the variation in metabolism within normal range being due to variations in body temperature has been but little considered. It is our custom to take the temperature by mouth each day before any measurement of metabolism is made. This aids us in ruling out any measurement with febrile temperature. It is recognized that temperatures by mouth are not so reliable as rectal temperatures, but at least an unusually high temperature is significant even when taken in this manner. In a study of the effect of sugars on metabolism and in a study of the effect of muscular work on sugars and on the metabolism of alcohol we have completed several series of experiments in which we have had both mouth temperatures at 8:30–9:00 a.m. and basal metabolism determinations shortly after. Table VIII shows the number of observations, range of oxygen absorption and of mouth temperatures, and the correlation coefficients between mouth temperature and oxygen absorption. Although only two of the coefficients are greater than 6 times the probable error, they are all positive and in the same direction, and indicate that the metabolism varies with mouth temperatures and that the latter are of some significance as an explanation of the variations in metabolism. The temperatures

TABLE VIII.

CORRELATION BETWEEN MOUTH TEMPERATURE AND OXYGEN ABSORPTION.

SUBJECT	NUMBER OF EXPERIMENTS	RANGE OF O_2	RANGE OF TEMPERATURE	CORRELATION COEFFICIENT	
		c. c.		r.	P. E.$_r$
J. C.	40	198–231	35.8–37.1° C.	+0.502	± .080
J. C.	55	202–235	35.7–37.1° C.	+0.386	± .077
J. C.	31	207–232	36.0–36.8° C.	+0.530	± .087
C. M. B. ...	41	238–283	96.1–97.9° F.	+0.407	± .088

at the upper part of the ranges are probably of more significance than those at the lower end. An early morning temperature of 96.1° F. undoubtedly is erroneous, whereas a temperature of 98.2° F. is of significance. It should be noted that but rarely is a "normal" body temperature of 98.6° obtained. In fact, 98.6° at 8:30 a.m. would be regarded by us as an indication of a mild febrile condition.

Effect of sleep. One of the conditions of the measurement of basal metabolism is that the subject shall not be asleep. It would be ideal if the measurement of the basal metabolism could be made with the subject asleep, because in this condition a person would be more likely to be completely relaxed and free from possible fear. The true difference, however, in different people between the metabolism asleep and that while awake is not so definitely known that we can apply a general value for making the comparison. The measurement of the oxygen absorption during sleep is difficult to make because the character of the respiration is likely to be irregular. Sleep affects the pulse rate and the respiratory quotient as well as the oxygen absorption. In general, the decrease in the metabolism due to sleep is about 10 per cent. Until recently measurement of the metabolism during sleep has been difficult, because of the lack of a suitable breathing appliance. None of the breathing appliances used for short periods has been reliable enough to prevent leakage during sleep. The helmet recently devised by F. G. Benedict (14) now makes it possible to study the metabolism during periods of sleep and periods when the subject is wide awake.

Hypnotic sleep. Whitehorn, Lundholm, Fox, and Benedict (15) found that simple hypnotic sleep might have an influence on basal metabolism by reducing the high figures obtained in training subjects, but did not reduce the rate below the normal value. In this respect, it differs from normal sleep.

Effect of mental effort. Basal metabolism is measured when the subject is awake, and under this condition, the mind is more or less active. It may wander from one thing to another or the person may concentrate intensely on a problem he has on hand in order to disassociate himself from the measurement and to prevent himself from becoming bored. A question that is frequently asked is, does mental "work" increase metabolism? Recently F. G. and C. G. Benedict (16) conducted a series of studies on six subjects to determine the effect of intense mental effort on the basal metabolism. The metabolism was first measured with the subject in a comfortable, reclining position, and in so far as possible, during mental vacuity. Then for one hour the subject was given mental arithmetic by a person reading problems of multiplication, such as 76 × 69. The subject signalled when the problem was solved, and was given another immediately. The metabolism was measured with the helmet respiration apparatus, both on the closed-circuit principle and on the open-circuit principle, with gas analysis. Table IX shows the effect of this intense sustained mental effort on the metabolism. On

TABLE IX.

EFFECT OF MENTAL EFFORT ON OXYGEN CONSUMED.

(c. c. per minute.)

SUBJECT	REST	WORK
I	208	210
II	212	219
III	232	241
IV	242	247
V	174	187
VI	181	191
Average	208	216

the average, the oxygen consumption was increased less than 4 per cent.

Standards of basal metabolism. For a number of years the Nutrition Laboratory collected data on the basal metabolism of normal men and women. In 1919 Harris and Benedict (17) evolved a set of prediction formulas for the average basal metabolism of men and women. These took into account the effect of height, weight and age and difference in sex. These formulas were based on metabolism data on 136 men and 103 women. Two other standards are also available, the Aub and Du Bois (18) based on body surface, and the Dreyer (19) based on age and weight. In general, the three standards give about the same results, because they are based upon practically the same original material. Benedict (20) has recently reported additional measurements on 34 men and 32 women. In both groups the average variation of the measured metabolism from the predicted was less by the Harris and

Benedict and Dreyer than by the Aub and Du Bois standards. It is found that the present standards for women are about 5 per cent too high. Benedict reiterates his belief that the heat production is determined by the active mass of protoplasmic tissue and by some existing stimulus to cellular activity. He is strongly inclined "to support the belief that differences in basal metabolism are more logically interpreted with reference to differences in age, height, weight, and sex rather than with reference to differences in surface area."

Effect of age on basal metabolism. Although the basal prediction formulas include a factor for the effect of age, this

TABLE X.

Age and Basal Metabolism. Calories per Kilogram per Day.

Miss W.		H. M. S.	
Age	Calories	Age	Calories
24	23.0	43	22.8
27	22.5	48	22.8
29	22.0	50	23.0
30	22.2	59	22.0
31	22.2	64	19.7
32	22.5		
33	22.8		
34	20.9		
35	21.0		
36	20.8		
37	19.9		
41	20.3		

factor is applicable to groups as a whole. So little is known about the effect of age with given individuals that no prediction can be made at the present time as to the possible variations in the effect of age on individuals who, although increasing in years, may still be in practically good health.

The Nutrition Laboratory has had the opportunity to follow the metabolism of 4 individuals for periods of from 17 to 24 years (21). Table X shows the series of values for the heat production per kilogram per day of a woman measured over a period of 17 years and for a man measured over 21 years. On the woman the series began in 1916 and on the man, in 1911. In the case of the woman there is a slight decrease in the metabolism per kilogram. Part of this decrease probably can be ascribed to a slight increase in weight, as she changed from a value in 1918 of 54 kilograms to a value of 60.5 kilograms in 1928.

With the man there has also been a gain, from 59 to 63.6 kilograms from 1911 to 1932, and there has been but little change in total calories per kilogram for the entire period of time.

TABLE XI.

AGE AND BASAL METABOLISM. CALORIES PER KILOGRAM PER DAY.

T. M. C.		F. G. B.	
Age	Calories	Age	Calories
30	27.8	38	22.5
32	26.4	39	21.6
34	27.8	40	21.6
35	26.6	41	20.6
36	26.9	44	20.7
40	26.5	45	21.1
42	24.6	46	20.8
46	22.8	47	21.0
49	22.9	48	20.6
54	23.5	50	21.1
		51	21.3
		52	23.3
		53	21.9
		55	20.4
		57	19.8
		61	20.1
		62	20.6

Table XI gives the results obtained on two members of the staff who have been connected with the Nutrition Laboratory since its beginning in 1907. With T. M. C. the first observations were in 1909, and there is a marked decrease in the values per kilogram from 27.8 to 23.5 calories at the age of 54. During this period of time the maximum change in weight was 3.5 kilograms, and there was an actual difference between the beginning weight and the last weight of 0.7 kilogram. The most marked decrease in metabolism was at the age of 46. The other subject shows likewise a decrease in metabolism per kilogram, but not so marked as with T. M. C. In 1917 at the age of 39, T. M. C. had typhoid fever. Whether this had any effect on the subsequent change in total metabolism cannot be stated, although for 6 months or more there was a marked decrease in activity. At the age of 44 T. M. C. purchased his first automobile and since that time has traveled almost exclusively by automobile rather than on foot and in street cars, as formerly. It is not improbable that some of the decrease in metabolism may have been due to a decrease in activity.

F. G. B. has been an extraordinarily active man during the entire period of observation. In fact, it is due to his inexhaustible energy and capacity for work and his continuous ingenuity in devising apparatus for over 25 years that most of the material is available for the substance of these two lectures.

The actual decrease in total calories for the two men over a period of 19 years was 283 calories for T. M. C. and 310 calories for F. G. B. In the Harris-Benedict prediction formula the same decrease per year is presented, regardless of the size of the individual. Many more observations are needed to establish the variations in the effect of age on the metabolism of the individual.

Elderly women. One of the marked gaps in the available data on the basal metabolism of normal humans is the lack of measurements beyond the age of 40. Recently Benedict and Meyer (22) determined the basal metabolism of 23 elderly women from 66 to 86 years of age and weighing from 32 to 72 kilograms. These women were all presumably in good health and none of them were bedridden. Most of them took care of their own rooms and some helped in the general care of the institution where they were living. On all bases of comparison the metabolism decreases with age. Beyond 78 years one might accept as a round figure 1000 *total* calories per 24 hours. Table XII shows the results of the measurements and the comparison by the three different standards of prediction. The variations from the predicted values for the different individuals were rather wide, from +14.9 to −16.9 per cent on the Harris-Benedict basis of prediction and the average deviation for the whole group was −0.8 per cent. The predicition by the Harris-Benedict standard was closer on the average than either of the other two bases of prediction. In general, there are such wide divergences that no existing standards may be considered to predict accurately the basal metabolism of individual elderly women. Therefore, until many more have been studied and more exactly measured the prediction of metabolism in old age may not be accepted.

Metabolism of Orientals. The standards for the prediction of basal metabolism were based entirely on observations with Caucasians, and at the time they were formulated there was

TABLE XII.

BASAL METABOLISM OF ELDERLY WOMEN.

Subject	Age	Weight	Total Heat Produced per 24 Hrs.	Per Cent Deviation		
				Dreyer	Aub-DuBois	Harris-Benedict
	yrs.	kg.	cal.			
I........	66	50	931	—18.3	—24.0	—16.9
II.......	68	71	1359	+ 1.0	— 2.0	+ 4.6
III......	70	72	1401	+ 3.6	+ 2.2	+ 7.1
IV.......	70	52	1112	— 3.6	— 3.9	+ 0.5
V........	71	72	1501	+11.2	+ 8.3	+14.9
VI.......	71	64	1149	— 9.5	— 9.9	— 5.5
VII......	71	67	1323	+ 2.0	— 5.1	+ 4.1
VIII.....	71	53	1096	— 5.3	— 8.4	— 2.1
IX.......	73	64	1318	+ 4.1	+ 0.9	+ 8.4
X........	74	63	1122	—10.6	— 9.8	— 5.5
XI.......	74	45	936	—11.5	—17.4	— 9.2
XII......	76	49	1148	+ 3.7	+ 1.4	+ 8.9
XIII.....	77	32	799	— 9.9	— 9.9	— 6.4
XIV.....	78	42	973	— 3.9	— 5.5	+ 1.8
XV......	79	69	1049	—19.5	—19.7	—14.5
XVI.....	81	67	1035	—19.0	—15.7	—12.8
XVII....	81	41	961	— 3.4	— 5.9	+ 1.6
XVIII...	84	50	1015	— 7.9	— 6.3	+ 0.3
XIX.....	84	44	1045	+ 1.4	— 3.5	+ 7.2
XX......	84	44	1070	+ 3.2	+ 5.6	+12.2
XXI.....	84	45	973	— 7.1	— 8.2	— 0.3
XXII....	84	63	966	—21.9	—19.4	—15.3
XXIII...	86	54	1026	— 9.7	— 9.7	— 2.0
Grand Average (Per Cent)..........				— 5.7	— 7.2	— 0.8

no indication but that they were applicable to all other races. However, in 1924 and 1925 MacLeod, Crofts, and Benedict (23) made some observations on the basal metabolism of 7 Chinese and 2 Japanese women, ages 21 to 29 years, who resided either at Mount Holyoke or Columbia University. It was found that the basal metabolism of these women was from 2.3 to 16.5 per cent below the Harris and Benedict standards, on the average 10.4 per cent below. Since these young women had been living under the same conditions as the other students at the institutions and having the same diet, it was suggested at that time that the metabolism of Orientals may be specifically lower than the English and American standards and that a racial effect in the direction of a lower metabolism be recognized with the Chinese and the Japanese.

Racial variation in metabolism. The observations of MacLeod, Crofts, and Benedict led the Carnegie Institution of Washington to undertake an extensive research in cooperation with investigators of other institutions on the basal metabolism

TABLE XIII.

MALE MAYAS IN YUCATAN. DEVIATION OF MEASURED METABOLISM FROM AMERICAN STANDARDS.

INVESTIGATOR		PER CENT DEVIATION
Williams		+5.2
Shattuck		+5.8
Steggerda:		
First Day	+9.2	
Second Day	+7.7	
Third Day	+8.2	
Average		+8.4
GRAND AVERAGE		+6.5

of a number of different races. On the occasion of an expedition to Yucatan in 1927, sent out by the Carnegie Institution of Washington and Harvard University, Dr. George D. Williams measured the metabolism of 32 male Mayas and found that the metabolism of the Mayas was, on the average, 5.2 per cent above the standards for white men of similar ages, heights, and weights (24). Three years later a second expedition to Yucatan was organized by Harvard University, working under the auspices of the Carnegie Institution of Washington. On this expedition measurements of the metabolism were made on 25 male Mayas under the direction of Dr. George C. Shattuck (25). Many of the subjects were the same as those that had been studied by Williams. The grand average deviation was +5.8% for the 25 individuals.

In a third expedition to Yucatan in 1931, carried out by the Department of Genetics of the Carnegie Institution of Washington, Dr. Morris Steggerda (26) measured the metabolism of 30 men and in order to solve the question as to whether the previous values may have been due to measurements only on one day, the observations were repeated on three different days. The grand average of all the values for percentage deviation of measured from predicted metabolism was +8.4. Table XIII shows the averages obtained on the three different expeditions. Coincident with these high values of metabolism

TABLE XIV.

FEMALE TAMILS IN MADRAS. DEVIATION OF MEASURED METABOLISM FROM AMERICAN STANDARDS.

SUBJECT	PER CENT DEVIATION	SUBJECT	PER CENT DEVIATION
1..........	—16.6	15.........	—17.3
2..........	—15.8	16.........	—26.5
3..........	—13.0	17.........	—15.0
4..........	—10.5	18.........	— 9.8
5..........	—18.1	19.........	—21.9
6..........	—19.2	20.........	—13.0
7..........	—21.4	21.........	—17.5
8..........	—16.7	22.........	—16.0
9..........	—12.3	23.........	—20.2
10..........	—20.5	24.........	—19.7
11..........	—12.1	25.........	—17.8
12..........	—18.0	26.........	—14.2
13..........	—25.2	27.........	—10.6
14..........	—29.8		

GRAND AVERAGE, —17.4

were low pulse rates, in fact, lower than usually observed with whites. In the last series many of the pulse rates were 45 or below. Similar low values were obtained by Shattuck and Williams, indicating that the high metabolism was in no way due to high heart rate.

In contrast to the metabolism of the male Mayas is the low metabolism of female Tamils measured by Professor Eleanor D. Mason at the Women's Christian College at Madras (27). Twenty-seven female Tamils were found to have invariably a low metabolism compared with the prediction. Table XIV shows the individual deviations for the 27 subjects and the average of the group as a whole, namely, −17.4 per cent. In the same institution another group of South Indian women, 17 Malayalis, showed an average of −16.1 per cent below the standards for American women.

These studies all indicate significant differences from American standards in the metabolism of the different races. The problem of variation in basal metabolism according to race is complicated by the factors of climate and of diet. However, the climate in South India and the climate in Yucatan are not so different as to suggest that climate plays the dominant rôle in the metabolism of these two races.

CONCLUSION.

We thus see that the determination of the basal metabolism is a fundamental measurement by which we may compare groups of individuals with respect to standards of nutrition, differences in race, effect of climate, and effects of such factors as influence human beings in masses. Knowledge of the basal metabolism is of such profound physiological importance that many more and careful measurements are needed before we can formulate the general laws governing the level of metabolism of each individual. Determination of the basal metabolism is of world-wide significance because it is applicable as a measure of vital activity to each human being.

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